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RESEARCH ARTICLE

Geology, Rock Geochemistry and Ore Fluid Characteristics of the Brambang Copper-Gold Porphyry Prospect, Lombok Island, Indonesia.

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Abstract
Brambang is one of the porphyry copper-gold prospects/deposits situated along eastern Sunda arc. This study is aimed to understand geological framework, alteration geochemistry and ore fluid characteristics of the prospect. Fieldworks and various laboratory analyses were performed including petrography, ore microscopy, rock geochemistry, chlorite chemistry and fluid inclusion microthermometry. The prospect is composed of andesitic tuff and diorite which are intruded by tonalite porphyries. Tonalite porphyries are interpreted as ore mineralisation-bearing intrusion. Various hydrothermal alterations are identified including potassic, phyllic, propylitic, advanced argillic and argillic types. Ore mineralisation is characterized by magnetite and copper sulfides such as bornite and chalcopyrite. Potassic alteration is typified by secondary biotite, and associated with ore mineralisation. Mass balance calculation indicates SiO_2, Fe_2O_3, K_2O, Cu and Au are added during potassic alteration process. Ore forming fluid is dominated by magmatic fluid at high temperature (450-600ºC) and high salinity (60-70 wt. % NaCl eq.). Hydrothermal fluid was diluted by meteoric water incursion at low-moderate temperature of 150-400ºC and salinity of 0.5-7 wt. % NaCl eq.

Keywords: Porphyry Cu-Au, Brambang, Lombok, Indonesia

1. Introduction

Lombok is one of islands within Nusa Tenggara province cluster. The island is situated in between Sumbawa island in the east, Bali island in the west, Indian ocean in the south and Flores sea in the north (Figure 1). Regionally, Brambang prospect located in south western part of Lombok Island is one of the porphyry copper-gold prospects/deposits identified along west-east trending Sunda-Banda Neogene magmatic arc (Carlile and Mitchell, 1994). In the eastern Sunda arc, several world-class porphyry copper-gold deposits/prospects have been discovered, such as Tumpangpitu in Banyuwangi, East Java, Batu Hijau and Dodo in west Sumbawa, and the latest discovery is Hu'u prospect situated in east Sumbawa (Harrison et al., 2018). Brambang prospect shows a typical porphyry deposit underlain by thick lithocap (Rompo et al., 2012) Only few studies and publications on Brambang prospect and its regional vicinity have been reported by, for instance, Rompo et al., 2012, Setijadji and Maryono, 2012 and Rompo et al., 2012 and Maryono et al., 2018. This study is particularly aimed to update information on the deposit geology, alteration geochemistry and ore forming fluid characteristics, which is at the end for a better understanding of the prospect.

Fig 1. Brambang prospect situated within west-east trending Neogene Sunda-Banda magmatic arc (modified from Hall, 2012).

1.1. Regional Geology

Southern part of Lombok island is composed of lithological sequences including Late Oligocene-Middle Miocene andesitic volcanic rocks and intercalated volcanoclastic rocks, which are associated with low-K intermediate intrusive rocks, and shallow marine sedimentary rocks and limestone (Garwin, 2002). Intrusive rocks are commonly cropped out along west-east trending belt of Lombok island. Diorite stocks or dykes are interpreted as the oldest intrusion, which truncated volcanic and sedimentary rocks (Mangga et al., 1994; Figure 2). Tonalite intrusion is spatially and temporally related to porphyry copper mineralisation. Diatreme breccia complex is mapped out in the periphery of dacite porphyry. The youngest rocks identified in the region is Quarternary volcanic products, which are preserved in the northern part of the island. The occurrence of diatreme breccia may indicate the late phase of magmatic activity, which terminated hydrothermal alteration in the region (Rompo et al., 2012). Mineralisation system in Lombok island consists of porphyry copper-gold, which is superimposed by high-sulfidation epithermal gold-silver. Due to north-south Late Miocene compressional regime, regional structures consisting of north-south extension, folding and trust faults, and NNW-NNE trending strike-slip faults.

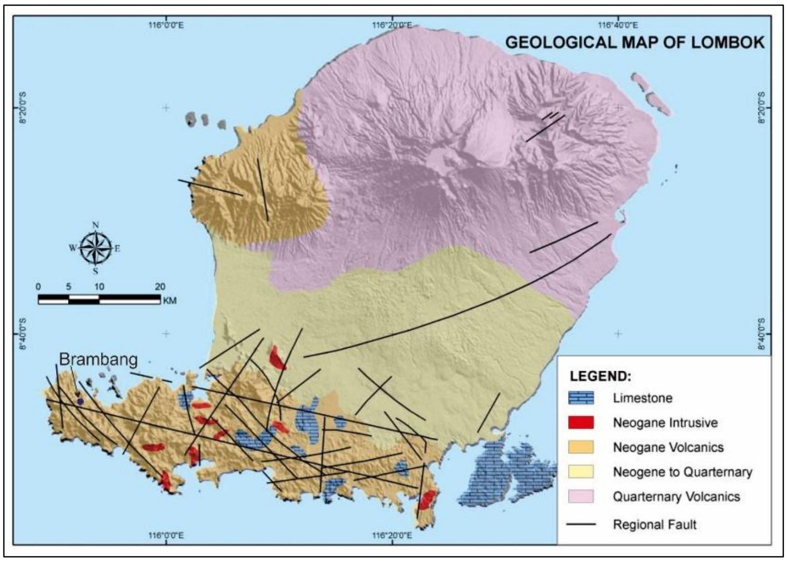

Fig 2. Regional geology of Lombok island (Mangga et al., 1994).

1.2. Analytical Methods

In general, research methods are divided into fieldwork and various laboratory analyses. Fieldwork was emphasized on geological and hydrothermal alteration observation. Some representative rock and ore samples were selected for further laboratory analyses. Laboratory analyses consist of mineralogy, bulk-rock geochemistry, ore chemistry and fluid inclusion. Mineralogical study was conducted through petrography and ore microscopy, which were done at Department of Geological Engineering, Universitas Gadjah Mada. Whole rock geochemical analysis using XRF (X-Ray Fluorescence) and ICP-MS (Inductively Coupled Plasma Mass Spectrometry) methods are to identify the major elements, trace elements, and rare elements in rocks. The whole rock geochemical data of the rocks were then used to calculate mass balance during the hydrothermal alteration process with the isocon method of Grant (1986). Atomic Absorption Spectrometer (AAS) analysis is used to detect metal element contents. EPMA (electron probe micro analyser) analysis for chlorite was done in Japanese Atomic Energy Agency (JAEA). Ore forming fluids are characterized by fluid inclusion microthermometric analysis. This analysis is performed by means of Linkam THMS 600 freezing and heating stage at Gifu University, Japan.

2. Results and Discussion

2.1. Lithology and Geochemistry

Brambang prospect is basically composed of three main rock types including lapilli tuff and diorite and tonalite porphyries. Two previous rock units are intruded by at least three stages of copper-gold bearing tonalite porphyries, so referred to as "old", "intermediate" and "young" tonalite porphyries, respectively. In study area, intermediate and young tonalites have a similar mineralogical arrangement, composed of hornblende, plagioclase, quartz, biotite, magnetite and minor ilmenite. Due to intensive alteration, old tonalite shows more obscured porphyritic texture, containing quartz, k-feldspar, plagioclase biotite and anhydrite. The tonalite porphyries are interpreted to be causative intrusions, which exsolved magmatic hydrothermal fluids, reacting with wallrocks to produce hydrothermal alteration and deposition of copper sulfides and gold. Ore mineralisation is in form of dissemination in the rocks and filling quartz vein/veinlet. Figure 3 is geological map of Brambang prospect showing distribution of tonalite porphyries and wallrocks. Tonalite porphyries as ore mineralisation causative intrusions are also recognized in Batu Hijau (Garwin, 2002; Idrus et al., 2007; (Idrus et al., 2009) and Dodo Elang (Harrison et al., 2018) in Sumbawa Island as well as Tumpangpitu in Banyuwangi, East Java (Hellman, 2010; Harrison et al., 2018).

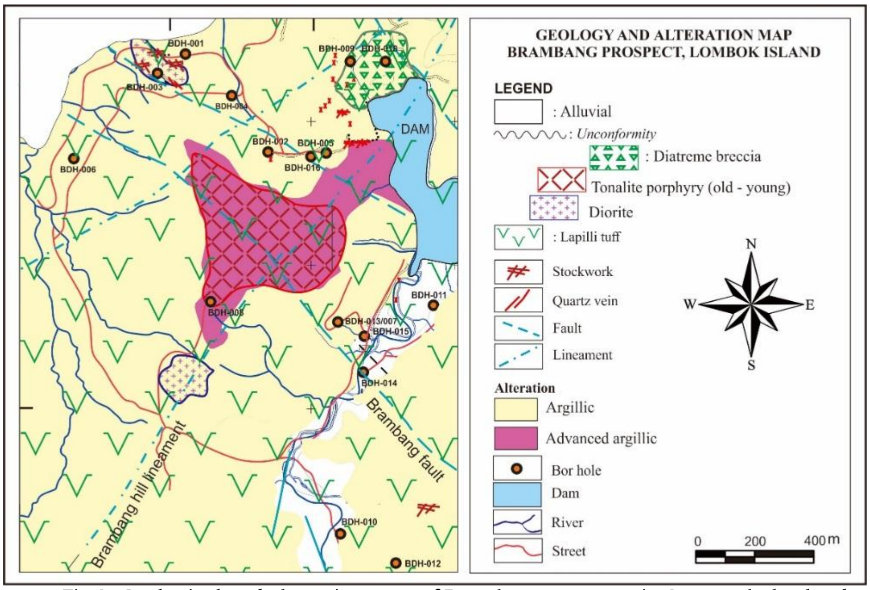

Fig 3. Geological and alteration map of Brambang prospect in SW Lombok Island (modified from PT. Buena Persada Mining Services).

Whole rock geochemical data of pre-mineralisation rocks such lapilli tuff and diorite as well as causative intrusions (tonalite porphyries) are tabulated in Table 1. Fig. 4 shows Nb/Y vs Zr/TiO_2 diagram from (Winchester and Floyd (1976) showing lapilli tuff is of andesitic and basaltic compositions. Andesitic-basaltic composition of magma may indicate an island arc setting of subduction (Rollinson, 1993). Bulk geochemical data of four tonalite and two diorite least-altered samples with LOI ≤ 5 wt.% are plotted on diorite and quartz diorite field of (Fig. 5A) and affinity of calc-alkaline series (Fig. 5B).

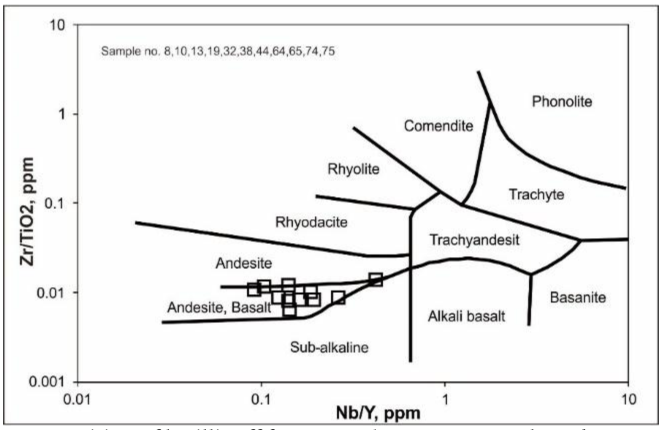

Fig 4. Andesitic-basaltic composition of lapilli tuff from Brambang prospect plotted on Pearce and Wyman (1996).

Table 1. Whole rock geochemical data of pre-mineralisation rocks and tonalite porphyry from Brambang prospect.

Rock Type	Kode Sampel	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LoI	Total	Ba	Nb	Y	Zr
Lapilli Tuf	13	61,39	0,76	15,50	18,58	0,00	0,21	0,20	0,87	0,83	0,32	6,71	100,36	310	1,6	13	83
Lapilli Tuf	8	55,42	0,83	17,29	8,60	0,26	3,51	5,61	3,59	0,14	0,14	0,17	95,56	44	3,5	25	100
Lapilli Tuf	38	63,87	0,65	14,98	10,56	0,41	3,06	2,64	1,52	0,40	0,22	4,33	100,64	76	3,4	21	77
Lapilli Tuf	65	55,85	0,82	20,86	8,43	0,13	4,19	1,62	3,35	2,40	0,08	1,69	99,41	120	3,1	22	67
Lapilli Tuf	19	52,83	1,22	24,71	17,34	0,00	0,11	0,03	0,21	1,78	0,10	13,92	100,25	270	2,6	6,2	86
Lapilli Tuf	32	63,42	0,85	20,89	12,04	0,00	0,09	0,16	0,32	0,32	0,17	10,14	100,40	160	2,7	14	100
Lapilli Tuf	75	62,57	0,90	19,59	13,32	0,00	0,07	0,19	1,04	0,76	0,22	19,43	100,09	370	2,9	11	99
Lapilli Tuf	44	60,52	0,90	21,16	9,22	0,01	0,67	0,34	0,74	4,07	0,26	8,38	100,27	140	3,3	32	76
Lapilli Tuf	64	64,79	0,72	13,95	9,65	0,26	4,58	0,84	1,76	1,06	0,22	3,91	100,72	100	4,1	22	69
Lapilli Tuf	10	61,98	0,56	15,96	8,04	0,12	2,43	2,34	4,33	1,81	0,19	1,91	99,67	320	3,7	26	85
Diorite	31	60,26	0,79	18,16	8,76	0,49	3,98	2,99	2,64	0,16	0,15	5,84	100,21	53	3,2	23	100
Diorite	25	57,61	0,73	19,21	5,54	0,14	2,53	5,27	4,33	1,25	0,11	2,64	99,36	100	3,6	19	72
Old Tonalite	17	65,58	0,45	13,70	8,74	0,14	1,87	0,91	4,44	1,15	0,10	2,44	99,51	330	2,7	12	72
Int. Tonalite	45	55,11	0,70	17,81	13,47	0,15	3,08	1,39	3,66	1,24	0,08	3,21	99,89	90	1,2	15	58
Int. Tonalite	33	60,64	0,91	18,58	8,42	0,20	4,39	2,37	1,04	1,12	0,16	1,00	98,82	120	4,1	20	95
Young Tonalite	72	61,16	0,55	16,55	5,68	0,08	2,29	6,41	3,57	0,75	0,14	1,75	98,93	280	4,4	14	88

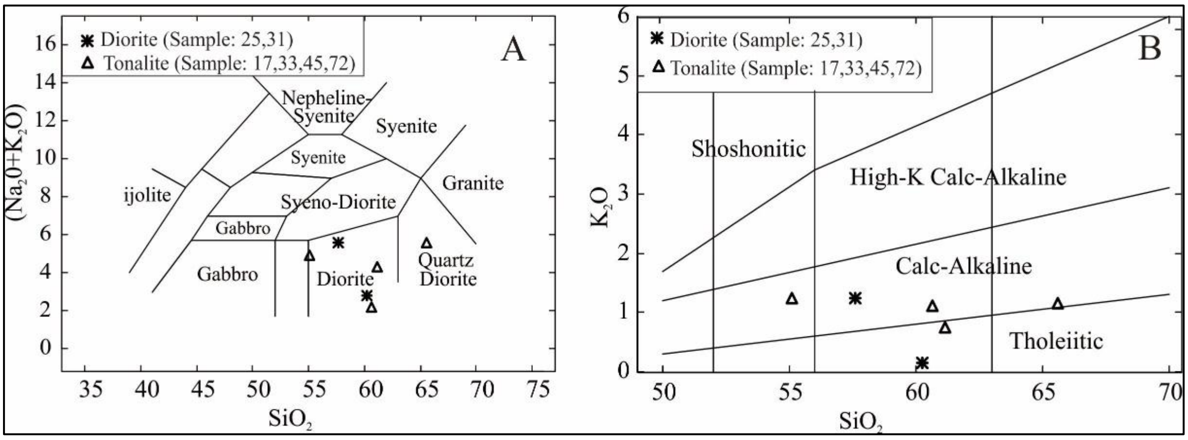

Fig 5. Tonalite porphyry and diorite from Brambang prospect plotted in diorite and quartz diorite fields of Wilson (1989) diagram (A), and mostly plotted as calc-alkaline affinity on Peccerillo and Taylor, (1976) diagram (B).

4.2 Hydrothermal Alteration and Ore Mineralisation

Five alterations types are identified in Brambang prospect both surface and subsurface including potassic, phyllic, propylitic, advanced argillic and argillic. However, on the surface, only two alterations are mappeable i.e. advanced argillic and argillic types (Figure 3). Potassic, phyliic and propylitic alteration zones were identified in drillcore samples. Potassic alteration is the earliest phase of hydrothermal alteration associated with the first tonalite intrusion. This phase is characterized by the process of forming secondary biotite from mafic minerals (hornblende and primary biotite).

Mafic minerals including hornblende and secondary biotite were chloritized particularly during phyllic and propylitic alteration. Chlorite geothermometry was applied on the basis of formula of Cathelineau (1988). The formation temperature of chlorite in propylitic-and phyllic-altered rocks from the Brambang prospect varies from 309 to 332°C. The chlorite formed at similar temperatures in both alteration zones which may suggest overprinting system by later stage of hydrothermal activity. Advanced and argillic alteration was superimposed on the earlier alteration zones such as potassic, phyllic and propylitic types.

Hydrothermal alteration processes result in mass changes altered rocks which can be in the form of gains or losses to oxides and minor elements in rocks. Mass balance calculations generally use the Gresens (1967)'s method modified by Grant (1986). To calculate the mass balance, representative samples of an altered rock, as well as an unaltered rock (or least-altered) were used. The immobile elements (Al, Ti, Ga, Hf and HREE as Tb, Dy, Ho, Er, Tm, Yb and Lu) are commonly used for isocon parameters (Ulrich and Heinrich, 2001; Hezarkhani, 2002; Idrus et al., 2009). The Isocon gradient is calculated from immobile element concentration of the original (least-altered) samples as precursor and altered rock samples. Mass balance of some potassic-altered rocks taken from drillcores have been studied in comparison to propylitic-altered rocks as precursor (Figure 6). When normalised to the propylitic-altered rocks, the potassic-altered tonalite shows a decrease in the mass and volume (6.54 ± 1.78 and 8.64 ± 1.74 %, respectively). In potassic alteration the main elements such as SiO_2, Fe_2O_3, K_2O, Cu, Au and S tend to be added, while MgO and CaO are depleted during alteration process (Figure 6). Those elemental gains and loses implies a strong association between potassic altered rocks (addition in secondary biotite) with ore mineralisation, which is marked by the presence of magnetite and copper-bearing sulfides. Copper and gold shows a positive correlation, and their grades increase by increasing of SiO_2 concentration (Figure 7). This may suggest that copper and gold grades increase with increasing the intensity of quartz vein/veinlet stockwork. Bornite, chalcopyrite, digenite and chalcocite are the copper-bearing sulfides identified in association with alteration type.

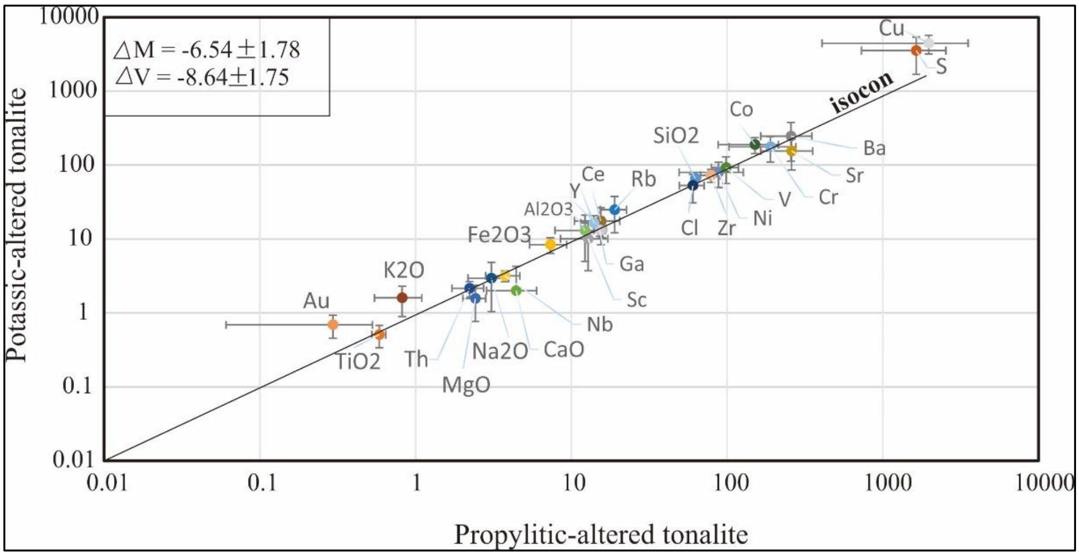

Fig 6. Elemental mass balance between propylitic-altered tonalite as precursor and potassic altered old tonalite porphyry.

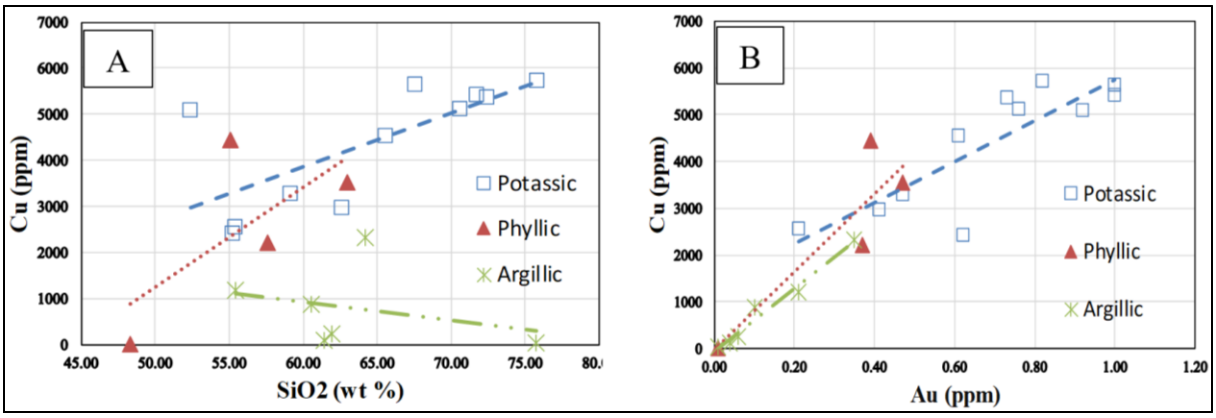

Fig 7. SiO_2 vs Cu (A) and Au vs Cu (B) diagram showing a positive correlation.

4.3 Ore-forming Fluid Characteristics

The quartz veins/veinlet system in the research area can be divided into five types including M, A, B, C and D (Gustafson and Hunt, 1975). Fluid inclusion studies were done for A, AB, B and D quartz vein/veinlet types. Nash (1976) showed three typical fluid inclusions found in porphyry deposit. Type I (L +V) called moderate salinity type, characterized by liquid phase volume more dominant rather than vapor phase and trace of the daughter minerals. Type II called (V-rich) type, characterized by dominantly vapor phase (>60%) to liquid phase, and frequently found daughter mineral such as hematite. Type III (L+V+S) called halite-bearing type, which mostly contain cubic halite, sylvite, hematite and anhydrite daughter minerals (Fig. 8). The type II and III fluid inclusions in type A, B, and AB quartz veins indicate high homogenization temperature of 450-600ºC) and high salinity (60-70 wt. % NaCl eq.) (Figure 9), which corresponds to pressure of ~300 bar and depth of ~ 3km from paleosurface. Fluid inclusion microthermometric data from D veins indicates low-moderate temperature and salinity fluid of 150-400ºC and 0.5-7 wt. % NaCl eq., respectively (Fig. 9).

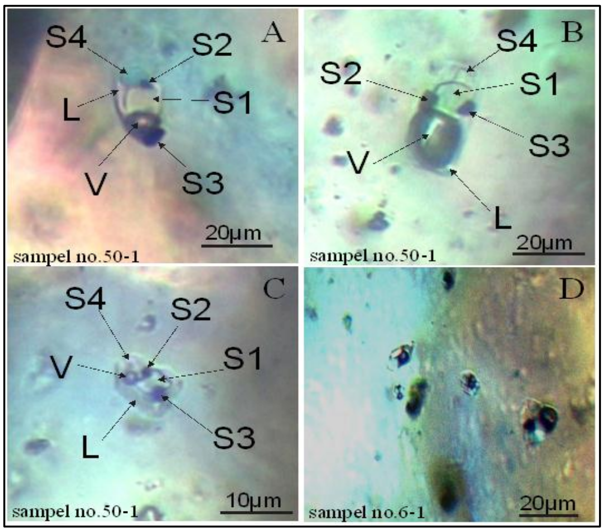

Fig 8. Petrography of Type III fluid inclusions (L-V-S1-S2-S3) hosted by A, AB and B quartz vein.

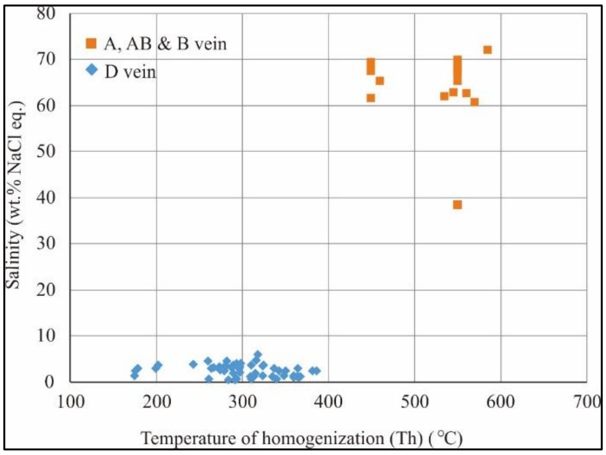

Fig 9. Temperature of homogenization (Th) vs salinity diagram of fluid inclusions hosted by A, AB, B and D quartz veins in Brambang prospect.

5. Conclusion

Brambang prospect shares some key features which are similar to the classical porphyry copper-gold prospect/deposits, particularly those occurred along eastern Sunda magmatic arc. The prospect is composed of three main rock types including lapilli tuff and diorite, which are intruded by at least three stages of copper-gold bearing tonalite porphyries, so referred to as "old", "intermediate" and "young" tonalite porphyries, respectively. The prospect is centered by potassic, phyllic, propylitic, advanced argillic and argillic alterations. Chlorite thermometry suggests temperature of formation for chlorite associated with phyllic or propylitic alteration varies between 309 to 332°C. Ore mineralisation marked by the presence of secondary magnetite and several high-temperature copper sulfides such as bornite and chalcopyrite is spatially and temporally rrelated to the potassic alteration. The addition of SiO_2, K_2O and Fe_2O_3 is along with the enrichment of Cu, S and Au during potassic alteration process. The Brambang ore mineralisation was originated by magmatic hydrothermal fluid at high temperature of 450-600°C and salinity of 60-70 wt.% NaCl eq., which corresponds to pressure of ~300 bar and depth of ~3 km from paleosurface. Fluid inclusion microthermometric data of D vein show low-moderate temperature and salinity fluid of 150-400ºC and 0.5-7 wt. % NaCl eq., respectively. This temperature might be representative of the formation of argillic and advanced argillic alteration.

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